PHYSICS IN INDUSTRY

VOLUME THREE

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PHYSICS IN INDUSTRY

VOLUME III

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ELECTRICAL PRECIPITATION

A LECTURE DELIVERED BEFORE THE INSTITUTE OF PHYSICS

BY

SIR OLIVER LODGE, D.SC., F.R.S.

PHYSICS IN INDUSTRY

VOLUME III

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INTRODUCTION

THE subject of Electrical Precipitation divides itself into two parts, the natural and the artificial. The natural has gone on in the atmosphere from time immemorial, small drops coalescing into larger ones, and all falling at a rate given approximately by Stokes's Theorem. Every water globule, being eight hundred times as heavy as air, must be falling through the air, and falling at a rate determined by its weight and size. It reaches a terminal velocity, which it does not exceed, as soon as the propelling force, that is the weight, is equal to the resistance, that is the atmospheric friction. And since one depends on the bulk, and the other on the surface, the terminal velocity for big drops is greater than that for small. Mist globules, or the particles which constitute a cloud, are so extremely small that they sink only slowly through the air. The slightest up-current can sustain them; so that by the general public they are often thought to float. But every drop of water must sink through the air at its appropriate rate. The large drops of a thunder-shower, and big hailstones, fall with some violence; though even they may be sustained by strong air currents, and may gradually grow, by condensation, until a hailstone can become as big as a walnut, or, I am told, in some countries as big as an orange—which must be a formidable missile.

A large liquid drop, however, will fall rather slower than the rate given by Stokes's Law for the same quantity of water, because it will tend to flatten out and no longer remain spherical. This flattening out may go on until it breaks up. There must be a maximum size of drop that can reach the ground; and often a minimum too. As for the very small drops, they seldom reach the ground at all: unless the air is thoroughly damp, they evaporate on the way. For, as Lord Kelvin showed, strong convex curvature promotes evaporation at the expense of condensation; while concave curvature promotes condensation. Hence it is that in the interstices of woollen and other fabrics, moisture tends to condense, and clothes become damp, before the ordinary dew-point is reached by a flat surface. Hence also the reason why some

nucleus is necessary to the formation of a mist globule; for no infinitesimal water drop could resist instant evaporation, and therefore could never form.

It has recently been discovered that a very efficient nucleus for the condensation of moisture is furnished by an electron; otherwise it might seem as if natural precipitation had nothing electric about it. But nature gives many other electric hints. The coalescence of small drops into large ones is assisted by electricity: and the late Lord Rayleigh threw a flood of light on this branch of the subject by numerous and long-continued experiments on the behaviour of drops and jets in the laboratory. Drops must often collide against each other, because, in so far as they are of different size, they fall at different rates. And though they may rebound after collision, yet if there is any perceptible difference of potential between them, they will unite when they collide, on the coherer principle. Thus meteorological phenomena are examples of natural electrical precipitation.

Artificial precipitation is likewise due to the aggregation of particles under electric influence. To bring it about, a brush discharge into air is necessary, and then all particles suspended in the electrified air—whether those particles be solid or liquid—tend to cling together, and are rapidly driven on to earthed or oppositely charged surfaces in their neighbourhood; so that the air is rapidly cleared of cloud or fume or dust. In cool stationary air, in a laboratory, the process is easy; but to carry it out effectively and continuously in a violent rush of hot air or vapour, on a large scale, has needed enterprise and invention, and is a notable example of Physics applied to Industry.

A third and shorter portion of this discourse begins to contemplate the possible application of Physics, in the future, to the modification of atmospheric and meteorological phenomena; especially in certain countries where control of the weather, or regulated precipitation of moisture, seems so desirable as to be worth the trouble and expense of making the attempt.

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ELECTRICAL PRECIPITATION

DELIVERED IN THE

HALL OF THE INSTITUTION OF ELECTRICAL ENGINEERS
LONDON

On 29th October 1924

BY

Sir OLIVER LODGE, D.Sc., F.R.S.

The Hon. Sir CHARLES PARSONS, K.C.B., M.A., LL.D., D.Sc., F.R.S.,
President of the Institute of Physics,
in the chair

PART I

NATURAL PRECIPITATION

PART I

NATURAL PRECIPITATION

EVER since Lord Armstrong's hydro-electric machine, and Faraday's investigation into the details of its working (*Exp. Res.*, vol. ii.), it has been known that drops of water, or mist globules, driven over a solid surface, become electrified; the sign of the electrification depends on the nature of the liquid and of the solid surface against which it rubs. Dry steam, or dry gases of any kind, will not do what is needful. There must be condensation; that is to say, the steam must be condensed into a visible cloud, in order that it shall become charged. The issuing steam, when clean, is usually positive, while the jet and boiler become negative.

This, after all, appears only an example, though rather a striking one, of the familiar but notable fact of frictional electricity. Any two surfaces rubbed together become oppositely electrified. And it is well known that the potential which can thus be attained, when the surfaces are separated, can be very high and can give rise to disruptive discharge.

The discovery of electrons has to some extent illuminated this process, but has also perhaps made it more surprising. It is evident that electrons are transferred from one body to another across the junction; this gives rise to a considerable charge, which rises to a high potential when the capacity is diminished by mechanical separation. When two metals are put into contact, a few electrons flow easily across the junction. Between two insulators an immense number can be forced across, but the exchange is less facile and may require the violence of rubbing to effect it—though whether the act of rubbing is completely understood, may be doubted.

As to the high potential which can be thus attained, each electron is already at so high a potential, at least when isolated, that it is hardly a matter for surprise. Assuming that the ordinary electric laws apply to a charged spherical body so small as an electron, its potential when isolated is comparable to 5000 electrostatic units, or one and a half million volts. And we know how amenable these highly charged and extremely mobile corpuscles are to the slightest electric force or gradient of potential. We also know that the outlying electrons of an atom—those which are responsible for chemical affinity—can readily link together two atoms, so that the link may be said to belong to either, and so that it might be readily transferred from one to the other; it is, as it were, common property for an instant, and it is almost a toss-up as to which side it ultimately adheres, when the surfaces are pulled apart. Any cause—sometimes quite a slight cause—which encourages a preponderance of

transfer in one direction may be said to explain frictional electricity; a difference in roughness or in colour may suffice, without any necessary difference of texture or substance. If the torn surfaces are really alike in every respect, it seems possible that the intermediate or uniting electron need adhere to neither, but might hover between them in such a state of uncertainty that a puff of air could waft it away. In other words, it might elect to cling to an obtrusive or alien atom, such as air, instead of to the substance to which it originally belonged.

So we are constrained to ask this question: When two precisely similar substances are rubbed together, or are put in close contact and separated, would a blast of air between them become electrified? The chances are that it would, if the contact were close enough to cause adhesion—as with Whitworth plates. The experiment should be tried.

Electrical Cohesion

In contrast to, or as the converse of, the electrical phenomena produced by the forcible separation or decoherence of two surfaces, we have the correlative phenomenon of the union or cohesion of two surfaces under applied electric stimulus. This is best shown by bringing into so-called, but unreal, "contact" two portions of the same substance; for instance, two water drops or two mercury globules or two metallic granules. Effective contact is not usually established by any light pressure unless there is some slight electric difference of potential between the surfaces. There is usually a separating film, it may be of oxide, or it may be of grease, or it may be of ordinary air; and until the separating film is either removed or punctured, cohesion does not occur. For very feeble electromotive forces, below that which is necessary to puncture or squeeze out the film, the surfaces are found to be insulated from each other; and we have the familiar phenomenon of "a bad joint"—the capriciousness of which has given plenty of trouble to wireless amateurs. It need hardly be said that there is no *real* capriciousness in nature. Caprice is always apparent, not real. (Possibly it is so in human relations too; but that is less certain.) The law of the bad joint is that for anything below a critical potential difference, it insulates; while for anything above that, it conducts, until the cohesion is mechanically broken again—a breakage or decoherence which with solids the slightest tremor can accomplish. And inasmuch as any bad joint in practice is liable both to tremor and to electric fluctuation, the reason of its capricious behaviour is obvious, and perfectly rational. A bad joint does not obey Ohm's Law in the least. It is a variable discontinuity, with laws of its own.

The laws of electrical cohesion were investigated by the late Lord Rayleigh, with his usual insight, precise carefulness, and accuracy. He dealt, not with the powder or filings of the ordinary coherer, but mainly with liquid globules, which were more amenable to experiment and calculation. If a small pool of mercury, lying in a flat dish or saucer, is cut in half by a slightly greasy knife, the two halves, though in apparent contact, remain separate. But if the two halves are connected to the

opposite poles of a battery, or even a single Grove cell, they reunite into a single pool again. Again, if two jets of water impinge on each other at an oblique angle, they will not unite if the water is clean, but will rebound from each other and continue separate, the two jets being insulated at their place of collision. So also the drops of a fountain of clean water can strike each other and rebound, thereby continuing separate and falling as fine spray. But if a volt or two of difference of potential between the two jets is applied by a battery, they unite and thereafter continue as one. So also if the drops in a fountain or shower are slightly electrified, they too are liable to unite whenever they touch; and thus they are apt to coalesce into big drops, not falling as spray or fine rain any more, but in blobs like a thunder-shower. This beautiful experiment of Lord Rayleigh's is quite easy to show, with a little care. The jet may advantageously be vertical, about two feet high, and emerge from a smooth glass jet $\frac{1}{25}$ of an inch diameter.

In 1884 I discovered that even the infinitesimal globules of mist or visible steam, if electrified, would unite with each other, so as no longer to be supported by the air, and would fall as Scotch mist or fine rain.

Again, it was found (by Robert Helmholtz, I think), that the light visible cloud of steam issuing from a kettle or other nozzle would, if electricity were discharged into it, appear much darker, becoming brown or orange coloured; would, in fact, change from the usual light grey appearance, and put on the gloomy and threatening aspect of a thundercloud. While, as every one knows, rain, and sometimes very heavy rain, is the natural concomitant of the atmospheric electric disturbance called a thunderstorm.

All this is evidently a case of electrical precipitation, and has remained in many of its aspects a puzzle till quite recent times. There are some things that are puzzling about it even now.

What is the source of electricity in a thunderstorm? Very high differences of potential are involved, amounting, I suppose, to some millions of volts. At any rate the length of the flashes is enormous. But whence comes the electrical separation responsible for these striking and even alarming effects?

Prior to 1909 this question could not have been answered, or would have been answered wrongly. It was thought that the charges probably came from the sun; and most likely charges do come from the sun, giving rise to Auroræ in the Polar regions. Arrhenius has attributed these luminous effects to the magnetic separation of the positive and negative ions, as they fly down from the sun towards the earth. And these electric projectiles appear to be intimately connected with the eruptive solar disturbances known as sun-spots. All that, in one form or another, may be, and probably is, true. But it does not seem to account for the familiar local thunderstorm. A solar effect is on too cosmic a scale. A thunderstorm seems to require a source nearer at hand, and more purely terrestrial, or even local; perhaps something more nearly on the lines of Armstrong's hydro-electric machine, something depending on friction between falling water-drops and the air.

An idea like this may have occurred to many, but it was not easy

to see how it could possibly work. If the drops in cloud or rain, or if any mist globules, could be supposed driven against solid surfaces in the upper atmosphere, the difficulty would be removed. But such a supposition seemed absurd. Nevertheless it was found by Lenard that when water-drops splashed, either on to a solid or a liquid surface—when a fountain fell, for instance, into its basin, the scattered drops had a tendency to be electrified. So that in the spray at the bottom of a waterfall, electric separation was manifest. A variety, this, of the hydro-electric effect, and presumably explicable somewhat on the lines of contact or frictional electricity. It was difficult to suppose that the mere breaking up of water into drops would cause electrification. It was thought that the drops must, as it were, rub against something, or else touch and come away, in order to be electrified. It did not seem likely that any friction of water on air would do what was needful for electrification.

Nevertheless the problem of thunderstorms was so insistent that a great meteorologist, Dr. George C. Simpson, took the matter up seriously, investigated the electrical condition of rain, made experiments in the laboratory on falling drops, that is on drops falling through air, obtained numerical or quantitative results, and applied familiar laws of electricity to those results; so as, in the opinion of many competent judges, to arrive at the theory of thunderstorms. This remarkable Paper was published in the *Phil. Trans. Roy. Soc.* in 1909, having been read in February of that year.

Simpson's Theory of Thunderstorms

The remarkable thing discovered by Dr. Simpson is the hitherto quite unexpected fact that the mere breaking-up of a drop by a current of air results in electric charge. When a large drop, falling through air, breaks up into small ones, the air goes away negatively charged, the water positively charged, the water having touched nothing but air. Experiments made previous to 1908 to detect such an effect had given negative results. Probably the experiments had not been very persistent, since such a result could hardly be expected on theoretical grounds. It came as a surprise, and has taken some time to be assimilated. Some chemists, among them Professor H. E. Armstrong, have indicated disbelief, or, at any rate, serious doubt. But, so far as I know, no experiments have been made to contradict the result; and I think it must be taken as substantiated. At any rate I propose so to take it. But surely it is extraordinary that the mere breaking-up of water should electrify it.

To attempt to understand it, we must look at it from the point of view of what I began with—namely, the electrical influence on cohesion. It may be regarded as the reciprocal or converse effect. Two globules unite under electrification; and two globules separating give rise to electrification. But whereas the combination must be a differential effect—that is to say, there must be some difference of potential between the two globules in order to break down the barrier, the separated

portions of a single globule are not differentially electrified. Both portions are positive, and may apparently be at the same potential. The opposite charge in their case belongs to the air, which has, so to speak, blown them apart. A large drop of water, falling through air, first tends to flatten itself by the viscosity resistance, and then presumably crimps itself into drops all round its horizontal circumference. Into how many drops it may break up I do not know, nor does it seem to matter. What is certain is that a big drop breaks up into smaller ones, and these, according to Simpson's experiments, are positively electrified with reference to the air.

The small drops naturally fall at a slower rate than the big one, and accordingly if there is an uprush of air, that is if they are falling through an ascending current, they will be carried upwards. But being electrified, they are just in a condition to cohere again as soon as they come into contact. For they can hardly all be exactly alike; they may differ either in size or in potential or in both, and Lord Rayleigh found that any difference, whether in size or in potential, facilitated recombination. Hence, sooner or later, the small ascending globules will coalesce into big ones, and then they will be able to fall again, once more to be broken by the up-current, and so carried up again, this time with an additional charge. This is Dr. G. C. Simpson's theory in brief; and he has adduced many meteorological facts which appear to justify it, and to show that the imagined process is one that is really likely to occur. The occasional sustaining of heavy matter by air currents is well known, and the production of large hailstones can hardly be otherwise explained. The sequence of operations: (1) coalescence of mist globules into falling drops; (2) breakage of large drops and carrying upwards; (3) renewed coalescence and falling again; may be repeated several times, until presumably the drops get so highly charged that they will no longer combine and fall. For, be it noted, though gentle electrification combines them, strong similar electrification will keep them apart; for they will repel each other, and so never come into contact. Recombination can only occur when they do come into contact. Hence when they are too highly electrified, they will be carried by atmospheric uprush to a higher stratum, where they can form part of a cloud. When they arrive among other uncharged mist globules, they can easily combine with them, and so once more grow into bigger ones, and fall. But if the uprush is sufficient, they will not reach the ground; they will be broken up again and recharged. And so the process will go on, until, by some horizontal drift, they escape from the up-current, and find a region where they can fall, even as big drops; thus constituting a thunder-shower round the edge or at the margin of the uprushing air.

There is thus a certain critical speed for an air uprush which will prevent any water from being able to fall through it. For small drops will clearly be carried up, and big drops will be broken into small ones. Hence no rain can fall through a sufficient uprush of air. The speed of air which would prevent water from falling through it is nothing excessive. The critical speed had already been measured by Lenard, and was found to be 8 metres a second, say 26 feet a second, or 17 miles an

hour. This, as Simpson says, is but a moderate wind; and, in storms, uprushes are known to be able to lift solid objects—showing that they are much more violent than the critical speed.

Discussion of the Theory in the Light of Cohesion

Now let us see if we can form any conception of what is happening when a drop breaks up under the influence of a vertical wind. To take a simple case, let the drop break into two. The two halves will be connected by a ligament, under the influence of surface tension; and when the length of that ligament is equal to its circumference, it becomes unstable, and snaps in two or more places, while its middle coalesces into a very minute drop or drops.

Now cohesion is known to be a form of electrical attraction. We may conceive of the two halves being held together by a surface layer of electrons, or what is called a double layer, straining across the gap. The electrons are more mobile than their positive correlatives: and when the snap occurs, it seems possible, though not easy, to imagine that electrons may be carried away by the air current. Whether the surface electrons are themselves blown away, or whether they crowd into the little drop which is formed by the broken filament, I know of no evidence to show. Anyhow they do appear to be carried away. Otherwise the remaining drop could not be positively charged. The air carrying off the electrons is thereby negatively charged; for even if the electrons are not isolated and bare, but belong to a small drop, that drop, being small, would almost instantly evaporate, with the ultimate result that the electrons are practically free; or possibly they attach themselves to the molecules of dry air, giving the known phenomenon of a charged gas.

Thus is effected electrical separation. The negative goes up, the positive stays down or partly down, until the vertical potential gradient rises to a critical value, say 30,000 volts per centimetre; which is well known to be sufficient to give a disruptive discharge or flash between two flat conductors. Probably, under the circumstances, a much less potential gradient than that would suffice — but something perhaps not hopelessly below that general order of magnitude.

Quantitative Estimate and Extension

Now let us look at the matter more quantitatively, making use of Dr. Simpson's excellent measurements. The drops he mostly experimented upon were a quarter of a cubic centimetre in volume, and therefore, when spherical, would have a radius of four millimetres. Such a drop, falling on a vertical jet of air, is blown to fragments; and the fragments, being collected, are found to have an aggregate charge of 0·005 electrostatic units. To provide such a charge it is easy to calculate that ten million electrons must have been removed from the quarter cubic centimetre of water, or say forty million per cubic centimetre. This seems a large number; and indeed it continues to be surprising that an

air current can effect this separation. Still, that is what the facts assert: and, after all, considering the number of atoms in a drop, ten million is a trifling number.

Let us think where they would come from. They would be on the surface, they would be, in fact, on the broken surface, let us say on the section of the filament when that snaps. So we can reckon the size of that filament which would suffice to supply ten million electrons in its cross-section, if each atom in the cross-section contributed one electron. The atoms in the stratum are 10^{16} per square centimetre. So the area of cross-section, in order to supply 10^7 electrons, would only need to be 10^{-9}. That is, its diameter would be 3×10^{-5}, which is the thirty-thousandth of a millimetre. This is improbably small; but then it may be unreasonable to suppose that the cohesion of the water is effected, at breaking-point, by one electron from every atom, and it is still more unlikely that every such electron would be blown away. If only one in a thousand of the cohesion-electrons were blown away, the cross-section needed would be 10^{-6}, and the diameter the hundredth of a millimetre: which is still very small. Hence, as far as quantities are concerned, there seems no difficulty about supplying the measured charge in this way.

Discussion of the Potential likely to Result

To go further into the matter, it will be well to attend to differences of potential, and to the tension across the separating film. Go back then to the split mercury globule or pool, with the two halves resting against each other, but not in contact, and consider the film separating them as something rather thicker than molecular dimensions, say, for instance, 10^{-7} or 10^{-6} of a centimetre. Lord Rayleigh showed that often one Grove cell could break down the film and effect junction; let us say 1·5 volt. Or perhaps for numerical purposes it would be better to take it as one volt; since with care it can be brought down to that, and at any rate it is of that order of magnitude. Taking the film as 10^{-6} cm. thick, the gradient of potential is a million volts per centimetre. This will equal $4\pi\sigma$, where σ is the surface density of charge. Hence σ is of the order 300 E.S. units, and the number of electrons which would give this surface density is 6×10^{11} per square centimetre. Or, in the section of a filament one-hundredth of a millimetre thick, 6×10^5, which is getting near the right order of magnitude for providing the 10^7 electrons required, as estimated two paragraphs above.

A film of thickness 10^{-7} cm. would give tenfold the density for the same minimum voltage, and ten times the number of electrons; but the film in that case would be of black-spot thinness.

The tension or mechanical force across the film—even a film that gives colours of thin plates—is considerable, being $2\pi\sigma^2=5\times10^5$ dynes per square centimetre; say half a kilogramme per square centimetre, or 7 lb. to the square-inch, even for 1 volt. It appears probable that it is this mechanical pressure which forces the drops into contact, squeezing out the residual film between the surfaces, or, at any rate, squeezing it out

in some one locality. For anything which promotes irregularity in the film, such as fine dust, promotes cohesion, by concentrating the tension in one or a few places, giving easy opportunity for the film to accumulate in local pockets without having to go far. And, of course, directly cohesion sets in at one point it rapidly spreads.

I regard then the breaking-up of the drop, and its simultaneous electrification, as the reversal of this cohesion process; and I look for a charge corresponding to the surface charge of the broken filament, which had been held together by a surface density of the order above reckoned.

It might seem likely that the steep gradient of potential across the film would give rise to puncture by disruptive discharge. But Lord Rayleigh adduces arguments against that view—though it certainly was a reasonable view, and may be legitimate as an alternative to that of squeezing together by hydrostatic pressure.

For our purposes it does not much matter whether the union is due to static pressure or disruptive discharge. All we need is the electrons straining across the gap, or across a surface which was a gap before reunion, or which becomes a gap directly the union is broken.

Once the separation is effected, the potential of course rises. The observed charge, 0·005 units, given to the original falling drop of four millimetres in radius, would raise its potential about four volts. The same charge shared among a multitude of drops, say n^3 in number, would only raise the potential of each to $1/n^2$ of that value, their linear dimensions being $1/n$th of the original. For instance, if the big drop broke into eight small drops, the radius of each would be two millimetres and the potential of each would be one volt. That is to say, we are still within the right order of magnitude for the potential which effects coherence, and therefore presumably within the right order of magnitude for the potential resulting from disruption.

Hence these theoretical and quantitative considerations tend to justify the rather surprising hypothesis on which Dr. Simpson originally based his theory and his experiments; namely, that the breaking of drops of water by an air current could give rise to electrification, and by repetition under reasonably likely atmospheric conditions could even generate the violent electric discharges of a thunderstorm.

PART II

ARTIFICIAL PRECIPITATION

The following references may be useful:

Nature, 26 July, 1883, vol. xxviii. p. 297. Preliminary Letter.

Phil. Mag., March, 1884. Paper on "Dust."

Nature, 24 April, 1884. Lecture to Royal Dublin Society.

Nature, 22 January, 1885. Lecture to British Association, Montreal.

Engineering, 5 June, 1885. Paper by Mr. Alfred Walker.

Proc. Roy. Inst. of Great Britain, 28 May 1886. "On the Electrical Deposition of Dust and Smoke, with special reference to the Collection of Metallic Fume, and to a Possible Purification of the Atmosphere"; also

British Association Report for 1885, pp. 744 *et seq.* "Electrostatic View of Chemical Action."

PART II

ARTIFICIAL PRECIPITATION

ARTIFICIAL precipitation, which is an interesting application of static electricity, dates for practical purposes from an observation which the late Mr. J. W. Clark and I made at Liverpool in 1884, though it was found that something of the same sort had been casually observed by a Mr. Guitard, and mentioned briefly in *The English Mechanic* of 1850. Indeed, I have just learnt, from an excellent article, "Precipitation Electric," by Mr. H. J. Bush in Thorpe's *Dictionary of Applied Chemistry*, that a certain Hohlfeld of Leipzig made a similar observation so long ago as 1824; so that this year is its centenary.

General Dust Phenomena

Mr. Clark and I began by an inquiry into the phenomenon of the dark plane or dust-free space rising from hot bodies, which is made visible by letting the air stream upwards into a horizontal beam of light. Dust in the air is said to make the beam visible; a fact which is more truly expressed by saying that the beam makes the dust visible. So if from any portion the dust is cleared away, leaving a dust-free space, there will be nothing to see in this portion. It will accordingly be quite dark, in contrast to the rest of the luminous matter surrounding it, and accordingly has the appearance of dark smoke. A similarly misleading appearance can be noticed when smoke is escaping from a room full of smoke through a window in daylight: the smoke looks as if it were coming in, because the fresh air blowing in looks much darker than the rest. Similarly, a spirit-lamp flame held below an electric beam looks as if it were smoky; but a hot poker does just the same. And Tyndall showed that the dust-free space had nothing to do with combustion or the burning up of the dust—though he did not arrive at the true solution.

Lord Rayleigh began to examine the phenomenon more critically, and found that quite a small excess of temperature, such as that of hot water communicated to a rod, would suffice to give a dust-free plane of singular definiteness and regularity, rising as a lamina from the rod.

Mr. Clark and I continued the investigation, and found that a warm rod was surrounded by a dust-free coat, which coat continually rose from it, so as to constitute the plane, and was continually renewed. All which was described in the *Philosophical Magazine* for March 1884, with illustrations of the effect. It appears that small dust particles cannot get into contact with a hot body, or even a warm body, but are

bombarded from it by molecular impacts—very much on the lines of Crookes' Radiometer; the force being more effective on the minute particles of dust than it is on the large vanes of the Radiometer.

The late Mr. John Aitken also took the subject up, and in many interesting ways showed that a warm surface would keep itself clear of dust, while a surface colder than the air would have dust deposited upon it. Molecular bombardment, somewhat on the lines of Brownian movement, drives the dust from a warm surface and towards a cool surface. So that whenever warm air streams near a wall, the wall gets blackened, as if the air had been smoky—giving to the wall or other surface a dirty appearance quite familiar above stoves and gas flames, and even above electric-light bulbs, out of which naturally no smoke or anything else can emerge.

After working at the subject in the autumn of 1883, Mr. Clark and I went on to examine the matter more closely with microscopes and other appliances; and, among other experiments, we electrified the rod to see what effect that would have. We found to our surprise that the dust-free coat thickened, and expanded, and rapidly extended into the box; in other words, that the whole box was cleared of dust by the electrification.

I then proceeded to electrify smoke, not on a small careful metrical scale by means of a battery, but in a larger and more violent way with a Voss or Wimshurst machine. The appearance was very striking. The smoke particles aggregated together like filings round a magnet, hovered in the air, after the fashion of the piece of gold leaf called "Mahomet's Coffin," for a short time, and then clung to the floor and the walls of the vessel, the effect being particularly rapid and efficient when brush discharge took place from a point. I also filled a bell-jar with steam, that is, with a visible cloud, and found that electrification caused the ultra-microscopic drops to cohere together, and fall as fine rain or Scotch mist.

I gave one of the Evening Lectures at the British Association Meeting at Montreal in August 1884, on "Dust," and there showed this effect on a fairly large scale, to the delight of both Lord Kelvin and Lord Rayleigh, who were present on the platform. This, one may say, was the beginning of artificial electric precipitation.

Practical Applications

Soon afterwards, Mr. Alfred Walker, of the firm of Walkers, Parker & Company of Chester, tried to apply the effect on a large scale in his smelting works at Bagillt in North Wales, where a quantity of lead dust escaped into the atmosphere, to the damage of the neighbouring agriculture. But the method of producing high-tension electricity in those days was rather primitive, and by no means of an engineering character. The difficulties of insulation were not properly appreciated by him. It is doubtful if any real electrification was communicated to the flues, along which the hot flaming and smoky gases were rushing at a considerable pace from the smelting furnaces: so that the first attempt at practical application was unsuccessful, and I presume was discontinued.

Some years later, however, the attempt was made again, after many large-scale laboratory experiments at Liverpool, by my son, Mr. Lionel Lodge. By that time the vacuum valves, which had been improved by myself and Mr. Robinson, enabled the discharge from an induction coil to be rectified; so that continuous high-tension electrification could be maintained from an alternating or intermittent dynamo current and transformer, in a more satisfactory and engineering manner than by an electrostatic machine, such as had been used by Mr. Walker. Moreover, the kind of electrodes most suited to the apparatus became known, after many experiments, and special elaborate insulators were constructed to hold them. It was found that the best results could be obtained by suspending oppositely charged metal surfaces alternately in a large precipitation chamber, alternate ones being provided with point or edge dischargers. There were difficulties connected with the clogging of the points or edges by the dust, and many subsidiary contrivances were devised before the arrangement became finally practical.

Meanwhile Dr. Cottrell, in America, had been working on somewhat similar lines, and had begun to apply the process to smelting and other work on a really large and successful scale. The Lodge Fume Deposit Company was also started in this country, and the two firms decided to amalgamate and co-operate, Dr. Cottrell always acting in the most honourable and friendly manner. His enthusiasm carried people along, and greatly helped the spread of the knowledge of the device in America.

I am told that a Dr. Moeller, in Germany, has independently taken out a number of patents, and that some of them are being applied on a large scale by the Metalbank Metallurgische Gesellschaft, who are also in friendly co-operation and have agreed to delimitation of frontiers.

During and since the war the process has been applied on a very large scale to take the dust out of blast-furnace gases, at four ironworks; the work proceeded under excellent facilities, because the dust was full of potash, which the Government required. The dust removed from blast-furnace gases is therefore of some value, a value which may be wasted, but which ought to be developed; but the chief advantage of removing it lies in the fact that dust-free gas burns much better, and therefore is more efficient for heating the hot-blast or for generating steam, without clogging of the flues or interfering with effective combustion and doing other damage. I may remind you that dust is actually used in collieries to prevent combustion and the spread of an explosion. So when you try to burn dusty blast-furnace gas, the flame is continually hesitating and retreating or going out, and often will not light; but when freed from dust the flame roars splendidly.

The recovered dust from some ores contains 20 per cent. of potash, and should be of considerable agricultural value; but it may also contain cyanide, which is deleterious; this, however, ought to be capable of removal. The quantities of dust to be dealt with may amount to a hundred tons a week. Blast furnace dust is singularly light, and therefore troublesome, as deposited: a ton of it more than fills a 10-ton truck. In an installation in which 20 tons a day are deposited, the gases rush past the electrode in volume 50,000 cubic ft. a minute.

I suppose blast furnaces represent the largest kind of installation in this country, since the quantities dealt with are so great. I must say I admire the engineering skill which enables continuous high-tension electrification, at a potential of nearly a hundred thousand volts, to be applied continuously night and day in enormous chambers to rapidly moving hot gas, with very little attention; so that some 95 per cent. of the dust is deposited, and so that tons of the solid material shaken off mechanically from the electrodes and collected in channels or chutes, are deposited every day and thrown down into railway-trucks below, and carried away. I am told that, in all, there were two hundred installations at work in the world a year ago.

Another installation, I may mention, is at the tin-smelting works near Bootle, north of Liverpool, belonging to Messrs. Williams Harvey & Co., where the tin-oxide fumes which formerly escaped into the atmosphere and constituted a nuisance are now saved, along with the smoke and other solid material from the furnaces, thus effecting great economy and paying for the electrification again and again. It is easy enough to re-smelt the recovered material; and thus a lot of valuable metal is saved, which would otherwise have been wasted.

Practical Details

Detailed information about some few of these installations is contained, with illustrations, in an Appendix. I need only say here that I am fairly well acquainted with some of the difficulties encountered by my sons in making large-scale application, and with some of the devices they have adopted in overcoming them. I will only refer to a few of these.

First of all the points or edges, and indeed all the surfaces, tend to get clogged with dust; so that periodically (about every three or four hours) everything has to be hammered or vibrated in some way. It is found best to knock the frames from below, by considerable weights hanging from levers above, which can be worked by hand, like railway signals; or else to arrange the knocking to be done automatically. The lighter hammering of the insulated and charged portions must, of course, be effected without earthing them; and that is done by a kind of projectile thrown or knocked up by the larger weight, which itself only hits the massive portion of the plant—the portion at zero potential.

Another feature where gases are treated at comparatively high velocity is that the dust collected on the surfaces tends to get carried along mechanically by the gases, unless pockets are provided in which it can accumulate—which it does mainly by means of eddies.

Another and more serious difficulty is the electrical surgings, which are always liable to happen from a large charged capacity, which surgings may damage insulation and give other troubles, but these are now understood and provided against.

Again, it is found that vacuum valves, though efficient enough on a small scale, are not suited to heavy engineering work; revolving commutators, synchronously driven by the alternating current supply, are used either to supplement or to replace the glass valves.

When everything is established and properly arranged, it is remarkable how little attention is required. The whole thing is set up in units, and each unit requires its separate periodical hammering; but short of that, and the removal of the dust, there is little or nothing to be done. The electrical appliances are so designed that they carry on without interruption throughout the year.

Naturally great precautions have to be taken to secure the safety of the workmen; no unit can be entered without unlocking the door, the key of which hangs on a hook, so arranged that when the key is taken off the hook, that unit is earthed and so put out of danger, without stopping or incommoding the electrical supply.

The installations are mostly of two kinds, "plate" and "tube." In a plate installation, the earthed portion consists of large flat or corrugated plates, with wire or comb electrodes between them—all, of course, elaborately insulated. In tube installations, the earthed portion consists of vertical tubes, the diameter being chosen to suit particular gas conditions. Down the axis of each a thin uncovered wire, say number 16 gauge, is hung from an insulator and kept stretched by a weight below.

To illustrate some of the curious unexpected difficulties which can be encountered and easily overcome when detected (though the detection is not an easy matter), it may be mentioned that in a sulphuric-acid chamber the insulation was constantly proving defective, in a way which could not be traced to any defect in the insulators. It was ultimately found that this depended on the shape of the weights which stretched the insulated and discharging wires. That shape had not been particularly attended to; for it would seem that any weight would serve to stretch the wire. But, in practice, a thin stream of acid flowed from the bottom of these weights, and thereby earthed them. The difficulty was readily overcome, when detected, by giving them flat bottoms or grooving them, so that they should drip instead of running as a continuous stream.

In some of the installations the gases are worked and the dust precipitated at a red heat: for instance, in the precipitation of iron oxide and dust from SO_2 gases generated by roasting pyrites for the manufacture of sulphuric acid by the Chamber process. The heat of the gas is utilised in Glover towers so that the dust has to be removed from the hot gases as it leaves the burners, and it is found that there is no necessity to cool it down. Subsequently further treatment of the cooled gases can be arranged to deposit sulphuric acid mist and impurities.

The sign of charge used in all cases is usually negative, the positive being sent to earth. The rate at which the gas streams past the electrodes is of the order of 7 ft. per second, but, of course, it varies in different cases.

By this time a good deal of experience has naturally been obtained. Different devices have to be used when dealing with different materials, and without experience it would be uncertain what kind of arrangement was most suitable for any particular case. Some materials are undoubtedly easier than others to deal with. Iron oxide seems

particularly easy. Tin and zinc and other metals are tractable enough. Lead, for some reason, seems more troublesome than others—the oxide is apparently too good an insulator and declines to receive a charge readily. It seems remarkable that sulphuric acid can be dealt with without undue difficulty, but I found that this could be done, at any rate on a laboratory scale, so long ago as 1888. (See a letter of mine in *The Electrician*, dated 5th January 1889, from which the following extract is made :

> " . . . So far as preliminary small-scale experiments on different kinds of fogs are concerned, they have all been done. Beside chemical smokes of various kinds, I have dispersed steam, and turpentine smoke, and coal smoke, and sulphur, and mixtures of all of them. I have made stuff like that in a sulphuric-acid chamber by burning sulphur and supplying nitric acid vapour, and steam from a boiler. All manner of nameless abominations have been tried, and all are amenable to the electrical influence.")

Smokes of Towns and Improved Combustion

It has often been suggested that this method of electrical precipitation of smoke and dust might be applied to the atmosphere of large towns. But the difficulties of applying it in the open air are very great ; and it has never seemed to me the right method of dealing with town smoke. Smoke is an extravagant thing to produce ; and it would be expensive, as well as dirty, to deposit it on the houses and people of a town. The right method of dealing with town smoke is not to produce it. Its production should be avoided by improved methods of combustion. Unfortunately, with ordinary methods, when water has to be heated, or steel slabs like armour-plate have to be annealed, smoky flames and smoke-laden spent gases are more efficient than those which are dust-free. For (1), combustion cannot go on in contact with relatively cool surfaces, like those of a boiler or armour-plate, and so inevitably the heat has to reach such surfaces across a gap by radiation ; and (2), clean air is a bad radiator, while smoky air is a much better one. But still it cannot be considered a satisfactory method to employ smoke for that purpose, any more than it is satisfactory to depend on the carbon in a gas-burner flame for the radiation of light. The scientific way is to realise that radiation is necessary, and to provide red-hot solid radiators—like highly magnified gas-mantles, which, in a clean and non-smoky atmosphere, can propel the heat through the ether whither it is desired. Contrivances for this radiant heat method of heating boilers have been devised and applied, by Professor Bone, in a manner which, if not as yet entirely successful (and on that I express no opinion), seems to me to contain the germ of the proper method of heating moderately cool surfaces, namely, by specially arranged and controlled solid radiation. The transmission of heat by mere convection from hot air, after flame has subsided, is not very efficient, especially if surfaces are clean ; but a black or dirty surface absorbs radiation perfectly well.

The other alternative (which doubtless has difficulties of its own) is to use conduction; that is to say, to protrude from the boiler, as part of its construction, rods or flanges long enough to extend into the flame and there to become red or white hot at one end. In that case combustion is not interfered with, the flame can touch the hot metal, and the heat thus received by solid metal would be freely conducted into the boiler. The gradient of temperature necessary to drive heat along a rod of metal is very much less than the discontinuous step of temperature needed to propel it across a film of air or of oxide, or any other insulating film or stratum. The difference of temperature, between the flame of a furnace and the boiler-plate which has to absorb the heat, is very great, maybe as much as a thousand degrees centigrade, or nearly two thousand Fahrenheit. It must be admitted that this drop of temperature is inefficient—as seriously inefficient as an unused waterfall: high-level heat is falling to low-level without doing any work, without achieving anything but its own transit. The *heat* need not be wasted; it may be got to enter the boiler, but great water-tube surface is required, and, if conduction could be utilised, the flow of heat from a flame into the boiler could be made much easier.

This is a digression from the subject of electrical precipitation. But the difficulty of boiling water without smoke is a real one; and the inefficiency of the temperature drop is deplorable; so in speaking to the Institute of Physics, I allow myself to refer to the subject once more.

It used to be thought that the incoming of the gas engine, where furnace temperatures exist within the actual working cylinder, would have the effect of dispensing with a great deal of steam production, and would thus get rid of this source of inefficiency—though the fact that the cylinder has to be water-cooled evokes another kind of inefficiency, for there again heat is flowing downhill without doing any work. But though large gas engines have arrived, and though a hopeful combination of gas and steam engine has been devised, in the hope of turning some of those difficulties into advantages, the invention of Parsons' steam turbine, one of the remarkable achievements of our time, has given to the utilisation of steam alone a new lease of life. For, although the production of steam is still an inefficient process, the utilisation of the energy in the steam by the modern turbine is about as efficient as can be imagined. Moreover, the device is so convenient and manageable that it is almost inevitably adopted: so that attention to the steam-raising problem becomes once more an alive and important necessity.

All these things may be superseded when the time comes for the utilisation of atomic energy, but that time is not yet. Whether our grandchildren will live to see it, on anything like an engineering scale, may be doubted. Time will show.

PART III

COMBINATION OF THE TWO; WITH SUGGESTED METEOROLOGICAL POSSIBILITIES

PART III

ARTIFICIAL METEOROLOGICAL POSSIBILITIES; OR COMBINATION OF NATURAL AND ARTIFICIAL PRECIPITATION

I HAVE now spoken of the natural and of the artificial kind of precipitation. But the modern fashion is not to leave Nature alone—rather to encourage and supplement it. Hitherto we have left large-scale atmospheric processes severely alone, and—as used to be done with diseases, plagues, and other ill-understood visitations, we have not attempted to coerce or control Nature, but have taken refuge in petition and appeasement of Higher Powers, in the hope that they will do what we have not the spirit or the energy to accomplish. Fortunately Pasteur has lived, and diseases have been taken in hand with some measure of intelligence and knowledge, and with results which are already profoundly moving. Doubtless much more remains to be done in this direction.

The Pasteur and Lister of the atmosphere have not yet arrived. Accordingly, though we have learnt that the precipitation of moisture depends on electrical conditions, and though rain comes down electrically charged, in a way which ought to give us a hint, we still supplicate Higher Powers for the production or the limitation of rain, instead of setting to work to see what we can do for ourselves.

I admit that the problem is a large and difficult one. But so are all problems, until we begin to tackle them. The atmospheric difficulties, however, are peculiar in this: they are on so large a scale that no ordinary laboratory experiments, or anything within ordinary private means, suffice even to make an experiment. Experiment is therefore left, in so far as it is conducted at all, to people—the so-called rain-makers—with some wit for influencing and interesting their fellow-citizens, and with some hope (so it appears to me) that the element of luck will intervene in their favour. The only thing that can be said is that any experiment is better than none, and that occasionally even what Darwin used to call a "fool-experiment" suggests a clue or bears some sort of fruit. But experiments conducted with more meteorological knowledge would surely be better: and now that it is possible to produce high-tension electricity on an extensive engineering scale, it seems to me that something ought to be attempted. Whether the stopping of rain or the production of rain is the easier problem, I am not sure; but what the greater part of the world suffers from is drought.

Now, if there are no clouds, or extremely little moisture in the atmo-

3

sphere, the case is hopeless. We cannot assume that any cause will put moisture into the atmosphere, except the sun. But I am told that in the countries suffering from drought, clouds do at times accumulate, but disappear without precipitation. Why should they not be electrified? Or, since they are probably already electrified, why should not the sign of the electrification be changed? Or again, why should not one part of a cloud be electrified differently from another part, so that the drops in it should be of different potential, and be likely to run together and coalesce? In other words, why should not natural precipitation be assisted artificially?

I know there are many difficulties. They may turn out to be insuperable; but that has not usually been the way with difficulties before, and we cannot tell what is insuperable until we try. The experiment would be costly, it would probably fail at first; there is much to learn, but there is also a good deal of knowledge to guide us; it would not be entirely working in the dark. Sooner or later the experimenters would gain a clue, some hint which might put them on the right track. They would very likely not start on the right track: they would have to mend their ways. They might encounter some ridicule; they might be discouraged by failure. But I feel that success awaits those, possibly of a future generation, who can put up with ridicule and who are not depressed by failure, but who persevere and overcome obstacles—which, after all, when we come near them, are seldom found as insuperable as we thought.

There were difficulties in navigating the Arctic Ocean, but Nansen overcame them in a pioneering manner. There were difficulties about exploring the Antarctic continent, but Scott and Shackleton and other noble men gave their lives in the attempt. There were difficulties in scaling the Himalayas, they seemed an insuperable obstacle. Whether the summit of Mount Everest has been reached by those two who died on one of its ledges, I do not know, nor do I know what result is to be expected if it has. But men will do these things; they do not seem to count the cost. They press on with enthusiasm, and leave the results to posterity. There were difficulties about making the equatorial belt of the earth habitable for white men, but Ronald Ross and the others worked at it—with what results we know.

There are difficulties about the electrical controlling of the atmosphere. Is that to be the one region of the earth over which man has no power, and about which he must succumb supinely to fate? I do not believe that it is. I feel sure that if the control of the atmosphere is felt to be an important problem, it will be tackled either now or by posterity. The considerations to which I have called attention in this lecture are such as to give some kind of clue, perhaps only the inkling of an idea. There are meteorologists who know far more about the atmosphere than I do. They will, I expect, be conservative in their estimate. It may be that physicists rush in where meteorologists fear to tread! But anyhow the problem strikes me as no more difficult than the problem of disease at one time appeared; and I venture to regard the future with hope.

APPENDIX

PRACTICAL NOTES ON COMMERCIAL PRECIPITATION

(Drafted by Lionel Lodge)

APPENDIX

IT is difficult to give general information, as each specific purpose usually requires particular treatment. As far as possible, certain types of plants are standardised for particular purposes, only varying in capacity and control arrangements; but variations in the temperature, speed, or content of the gases may involve considerable alterations in the precipitator chambers, and this again may affect the potential necessary, insulator design, methods of dust removal, and so forth.

The accumulated experience from over two hundred plants makes it possible (given information as to composition of gases, temperature, rate of flow, nature and quantity of suspended particles) to determine the most suitable type of treater for practically any fume problem, and to calculate closely the efficiency obtainable, power consumption, drop in temperature, etc.

The different uses to which the process has been applied may be grouped under the following headings: Acid fumes; waste gases from metallurgical processes; combustible gases; air cleaning; miscellaneous dusts.

Publications have been made concerning particular installations for all these different uses, so only one or two examples will here be given.

Sulphuric Acid Plant

In the manufacture of sulphuric acid from pyrites or spent oxide, for instance, the process is used to remove the dust from the hot sulphur dioxide gases as they leave the burners. The dust, which consists largely of oxides of iron, is of no value, but constitutes a nuisance in the subsequent processes, as it tends to choke up the Glover towers and discolour the acid.

When sulphuric acid is made by the contact process, it is essential to remove all traces of dust and other impurities likely to injure the catalyst. Two separate treaters are employed. One deals with the hot gases as they leave the burners at a temperature between 450° C. and 600° C., where the dusts and any solid particles are removed. The other deals with the gases when cooled. The precipitator at this point removes traces of arsenic and other impurities as well as precipitating any acid mist, the operating efficiency of this process in actual commercial use being over 99 per cent.

A type of installation for removal of the dust is shown in Fig. 5. This plant consists of horizontal twin chambers carried on a steel framework, the walls being built of brick 18 in. thick to avoid, as far as possible, loss of heat. The gases enter from the burner house on the extreme right. The overhead main can just be seen entering the valve tower near the top. The gases pass downwards through cast-iron valves 3 ft. in diameter, then between the collecting electrodes, which, in this type of chamber, are made of heavy-gauge wire mesh hung vertically and suitably stiffened to maintain a flat surface; this construction is used on account of the high temperature, the whole of the inside being more or less red hot. These collecting electrodes are arranged in four separate banks, each bank consisting of six electrodes equally spaced across the chamber so that there is a free passage between

them for the gases, which pass over, not through, the surface of the electrodes. Midway between each pair of collectors are hung the discharge electrodes, consisting of a plain fine wire attached to suitable fittings to facilitate quick erection and easy renewal. These electrodes are spaced about 6 in. apart and supported on frames, top and bottom, to hold the electrodes taut, the frames being carried on high-tension insulators. Inspection doors are arranged immediately below each bank of electrodes. These are conspicuous on the photograph. Below these doors are the dust hoppers with mouth-pieces and slides to empty the dust into the trolleys running on rails below.

Each half of the twin chamber is identical with the other. Normally the gases pass through both sides, but either side can be shut off for removal of dust. During this period all the gases pass through the other side. Removal of the dust is a simple and quick operation, taking only a few minutes. The valves at each end of the chamber are closed and the hoppers opened ; most of the dust is immediately emptied out, but rapping gear is provided to tap the electrodes slightly in order to remove any dust which may be left adhering. The hoppers are large enough to carry two or three days' collection of dust, so that the time spent in looking after this plant is negligible. In the ordinary way it works with little or no attention.

The speed of the gases varies, but 7 ft. per second may be taken as an average velocity. Uni-directional current is supplied at a potential of about 60,000 volts, the power consumption being about 3 kilowatts for plant to clean the gases from a pyrites burner of 18 to 20 tons per 24 hours capacity.

Tin Smelting Plant

A plant erected in this country about three years ago and treating the waste gases from a Tin Smelting Works may be taken as a typical example of a precipitator for dealing with fumes from metallurgical processes. It employs pipe precipitators, the pipes being 9 in. in diameter, with 48 pipes to each unit ; there are fourteen such units. The lower part of each unit consists of a ferro-concrete box in which the dust is collected. This box is some 12 ft. square and about the same height. The gases enter near the top, then pass downwards round the pipes and upwards through the pipes into the top header, and away. Large cleaning-out doors are provided for periodically raking out the collected fume of which there is considerable bulk. This fume used to escape from the stack in the form of black smoke, and constituted a serious nuisance in the district. Since the precipitator was put in operation the visible discharge from the stack is merely a wisp of steam. The weight of dust collected amounts to 3 or 4 tons a day. This dust carries a fairly high tin content. The process is continuous day and night, being shut down only once a year for general cleaning.

The Transformer House equipment of five units is arranged so that any precipitator can be connected to any transformer unit, each of these units having nominal 25 K.V.A. capacity. The transformer and all high-tension parts are elaborately screened, so that it is practically impossible to approach any high-tension conductor while the current is on. Automatic safety switches earth each section when any door is opened, and the circuit breaker on the primary side of the transformer cuts off the current. In the precipitator house all the doors are locked and controlled by a master key, so that before any door can be opened the key has to be obtained, and this automatically earths that entire section. The operating pressure of this installation is approximately 80,000 volts.

Blast Furnaces

The cleaning of blast furnace gas is an example of precipitators in the third group (combustible gases). These installations handle a large volume of gas amounting to several million cubic feet per hour, and the dust collected, which is extremely fine and light, amounts to many tons per week.

The installation shewn in Fig. 6 has a capacity of approximately 4 million cubic feet per hour at working temperature, and handles the gases from two blast furnaces. There are eight separate precipitating chambers. The gases enter on the far side of the building from a 6 ft.-diameter main, then pass straight through the chambers, which are about 30 ft. long, and enter the delivery main. The collecting electrodes in each chamber consist of narrow plates, about 10 ft. long, spaced about 9 in. apart. Between each pair are the discharging electrodes with a series of points facing towards the collecting sheets. The gas has an unobstructed path between the electrodes and passes straight through, but the dust particles as they enter the electric field become charged, and are precipitated on to the collectors to which they adhere, the dust gradually building up in this way to a depth of 2 in. or 3 in. Rapping hammers free the collectors from dust. These hammers are operated once every four hours, the dust falling into the hoppers below. The crude gas on an average carries about 5 grammes of dust per cubic metre, though this varies considerably according to the class of iron being made and the ore smelted.

This plant has been in operation for practically four years; it is at present operating with only one furnace in blast. The dust collected amounts to about 30 tons a week, but this does not give a good idea of the enormous bulk of the dust, as it is extremely fine fume.

The electrical transformer equipment of this plant, which consists of four 25 K.V.A. standard sets, is housed in a building above the precipitator chambers, and each of the four units supplies current to two chambers. The whole plant can be operated by one attendant, apart from the handling of the dust. The dust is removed on day shift only, the hoppers being large enough to take care of a twenty-four hour collection. The removal of the dust from the blast furnace gas enables the gas to be burnt efficiently under boilers and stoves; approximately only two-thirds of the gas is required for the same heating when the dust has been removed. When clean gas is used there is considerable saving in coke required for the furnaces, which often amounts to 2 or 3 cwt. of coke per ton of pig smelted; in many cases the output of the furnaces is substantially increased, owing to higher blast temperatures and pressures and more uniform working.

The plate type of treater is not always suitable for gas conditions, and a pipe treater is sometimes more convenient. Fig. 7 shows such a pipe treater in course of erection. The installation shown has been in operation for over two years; there are six units, each unit consisting of 64 pipes. The gases in this installation enter through a 9 ft.-diameter main into the upper part of the hoppers below the pipes, then pass upwards through the pipes into the top headers, and away into the clean main, also 9 ft. diameter. This installation is cleaning the gas from three blast furnaces and has given remarkably good results.

[Table overleaf

Mr. P. E. Landolt, Chemical Engineer, Research Corporation, U.S.A., in a Paper gives the following Table of Data.

	Metallurgical Dust and Fume (Large Installation).	Metallurgical Fume.	H_2SO_4 and Precious Metals.	H_2SO_4 Mist.	Precious Metal Fume and Dust.	Metallurgical Fume and Dust.	Air Cleaning (Gold Dust).	Metallurgical Dust.	Metallurgical Dust.	Pyrites Burner Dust.	Producer Gas (Tar).
Investment per cubic feet gas treated	\$0.50	\$2.38	\$3.75	\$3.75	\$2.85	\$2.50	\$0.95	\$1.50	\$0.67	\$3.75	\$3·00
Cleaning cost per 100,000 cubic feet gas treated per hour . .	\$0.03	\$0.13	\$0.22	\$0.25	\$0.23	\$0.175	\$0.08	\$0.08	\$0.03	\$0.155	\$0.15
Temperature of gases treated .	250–300° F.	600–700° F.	150° F.	150–200° F.	650° F.	600–700° F.	70° F.	400–500° F.	300–400° F.	900–1000° F.	70° F.
Power consumption, kilowatt-hour per 100,000 cubic feet gas treated	0·3	1·6	2·8	2·0	2·4	2·0	1·0	1·0	0·2	0·1	1·25
Cleaning costs per 100,000 cubic feet gas treated at 70° Fahr.. .	\$0.05	\$0.26	\$0.25	\$0.30	\$0.48	\$0.35	\$0.08	\$0.14	\$0.04	\$0.50	\$0.15
Weight of gas treated in tons per hour, approximately . .	4000	50	26	8·4	8·0	14·4	53	66	270	18	. .
Efficiency of removal of suspended matter	85–90%	98+%	99+%	99+%	99+%	97+%	95+%	95 %	91 %	99 %	99%
Weight of precipitate in lb. (average) per 100,000 cubic feet, approx.	6	16	5–15	125	3	8–10	1·0	40–50	. .	7·5	15

Note.—Gas volumes taken at temperature of treatment, except where otherwise specified.

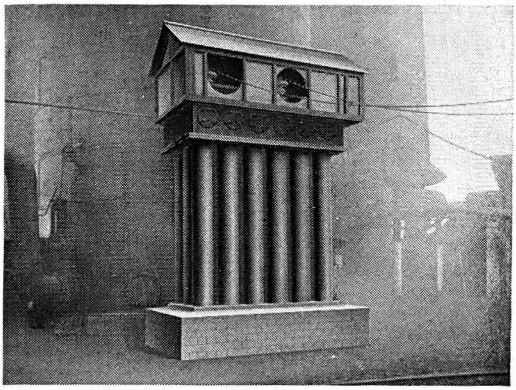

FIG. 1.

A small experimental pipe precipitator, with electrical arrangement on top.

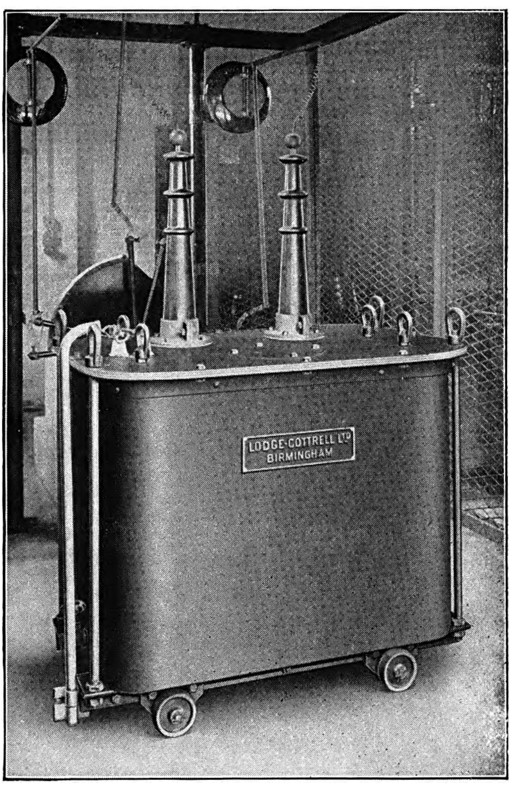

Fig. 2.

One of the transformers used.

Face p. 40.]

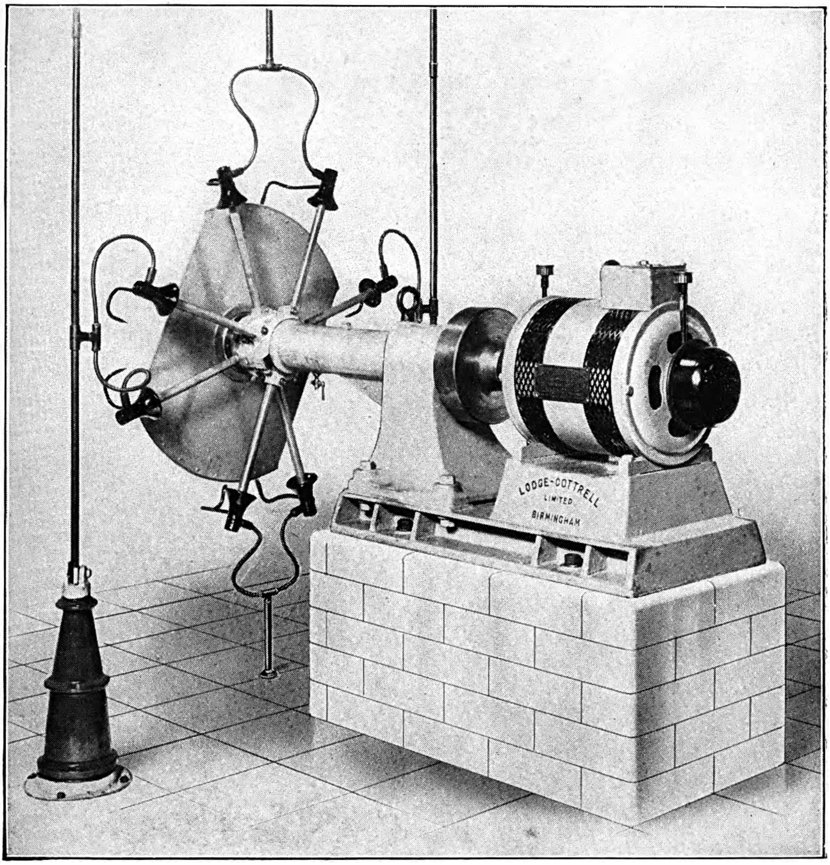

FIG. 3.

A rectifier driven by synchronous motor.

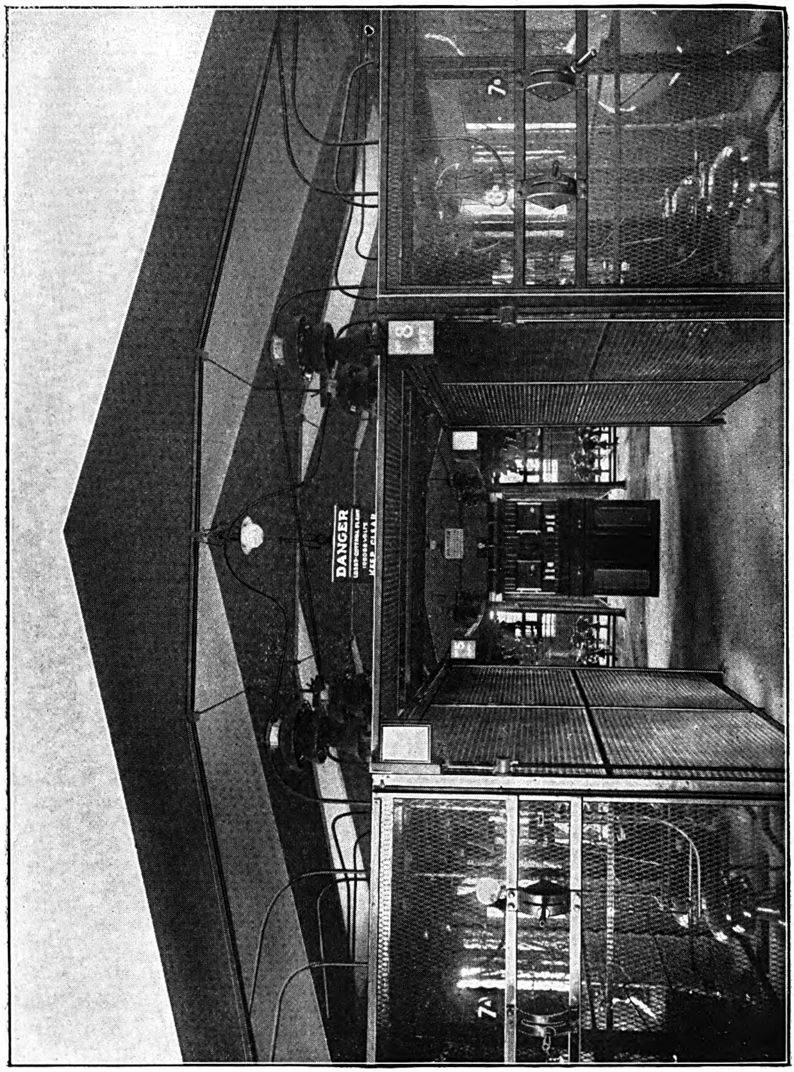

FIG. 4.
High-tension control room.

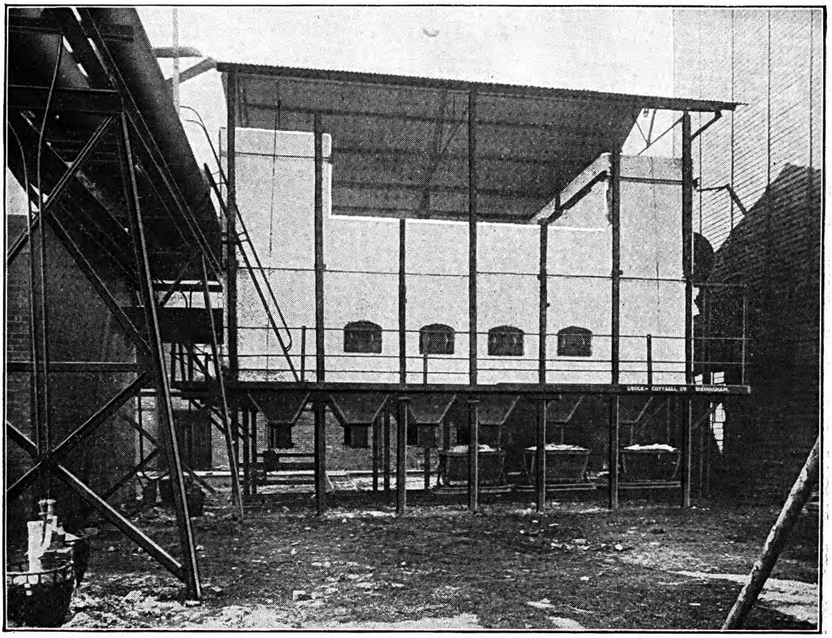

FIG. 5.

A precipitation chamber for dealing with hot gases from a pyrites-burning furnace, with hoppers below for dust removal by trucks.

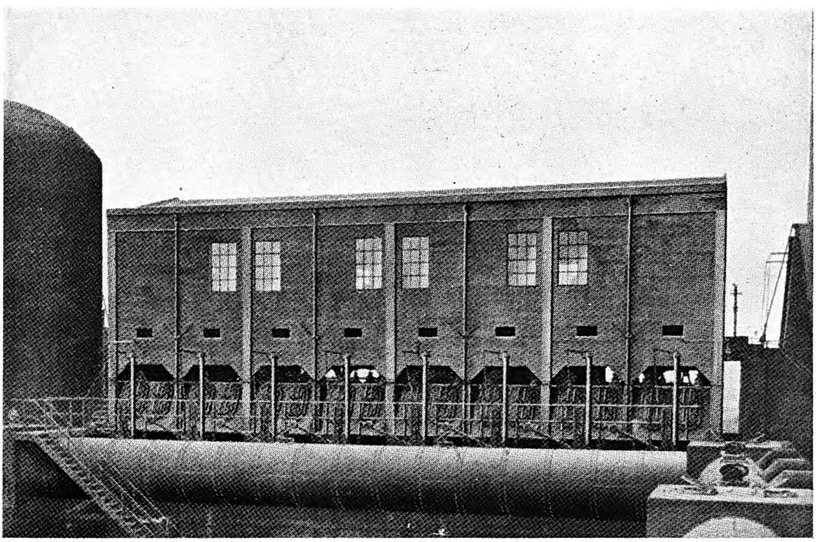

FIG 6.

Fairly large installation of plate type, for cleaning blast furnace gas, erected during the war. Transformer house above depositing chamber.

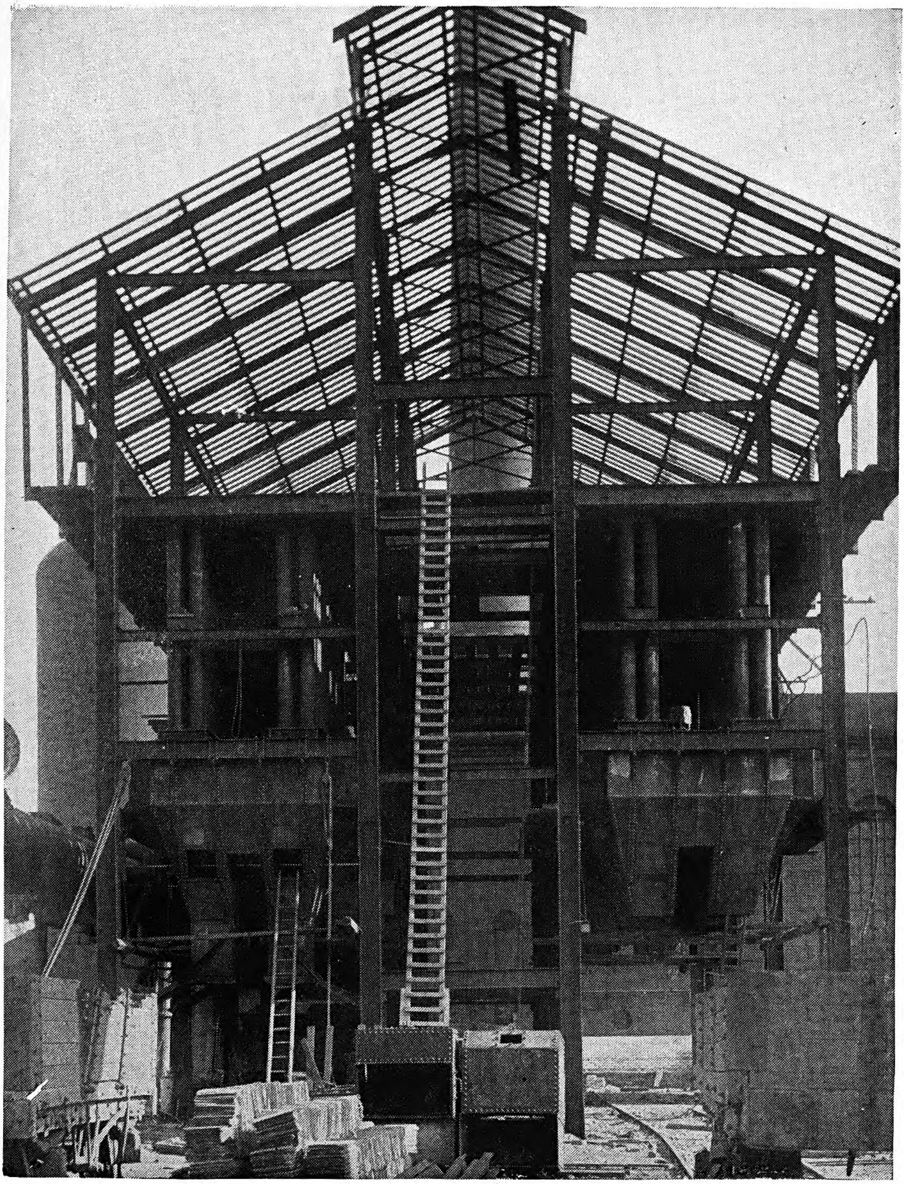

FIG. 7.

A large installation shown in course of erection, with electric control chamber above tube depositors in the middle, and hoppers and railway below.

Date Due

Nov 11			